# Can Mars Seismic Events be Successfully Modeled as Volcanic Tremor

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# Tremor Source Model “Volcanic tremor: Nonlinear excitation by fluid flow” [*Julian*, JGR, 1994]

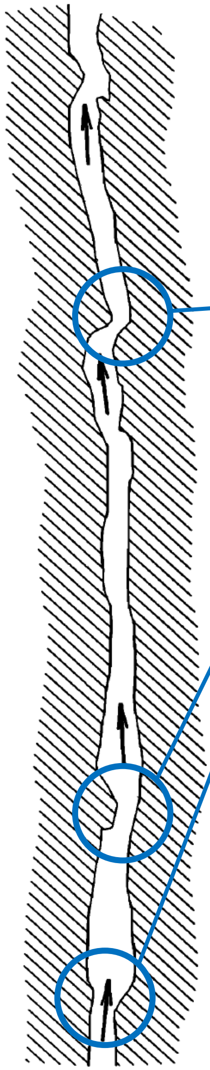
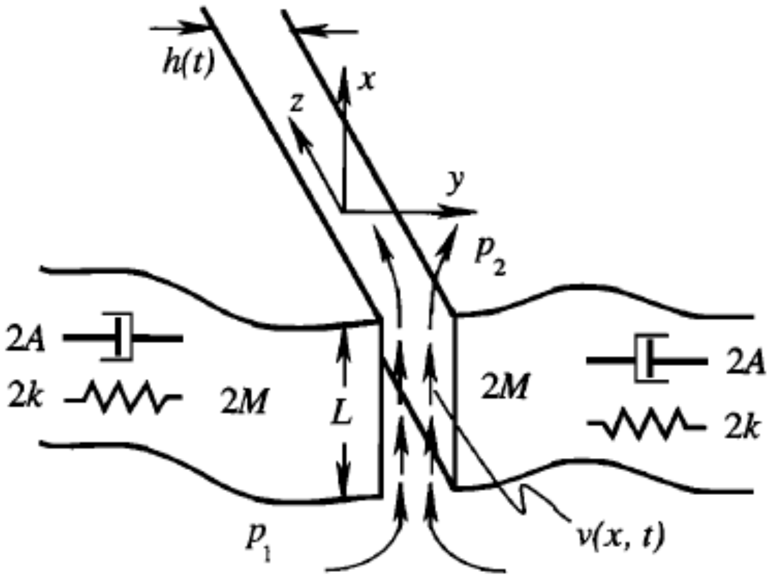


**Figure 7.** Schematic diagram of fluid flowing through an irregular channel in a volcano. If the flow at constrictions is vigorous enough, it can excite sustained oscillations.




Fluid equation of motion:

$$\rho\dot{v} + \frac{12\eta}{h^2}v = \frac{p_1 - p_2}{L}$$

Viscoelastic response of channel walls:

$$\left[M + \frac{\rho L^3}{12h}\right]\ddot{h} + \left[A + \frac{L^3}{12h}\left(\frac{12\eta}{h^2} - \frac{\rho}{2}\frac{\dot{h}}{h}\right)\right]\dot{h}$$
$$+k(h - h_o) = L\left[\frac{p_1 + p_2}{2} - \rho\frac{v^2}{2}\right].$$

- $g_M$ Mars g, 3.711 [m/s$^2$]
- $D$ Crack Depth [m]
- $p_1\_p_2$ Ratio p1/p2
- $p_2 = \rho \times g_M \times D$ Pressure in exit reservoir [Pa] = lithostatic
  $\mathrm{p1} = \mathrm{p}_2 \times p_1\_p_2$ Pressure in feeding reservoir [Pa]
- $k$ Wall elasticity [Pa] (Channel Aspect Ratio)
- $\rho$ Wall density [kg/m^3] =~ (magma density)
- $A$ Elastic damping [kg s]
- $\eta$ Fluid viscosity [Pa s]
- $L$ Channel length [m]
- $h_0$ Channel equilibrium thickness [m]
- $M$ =~ $\rho \times L \times L$ Wall mass [kg/m] (2D)

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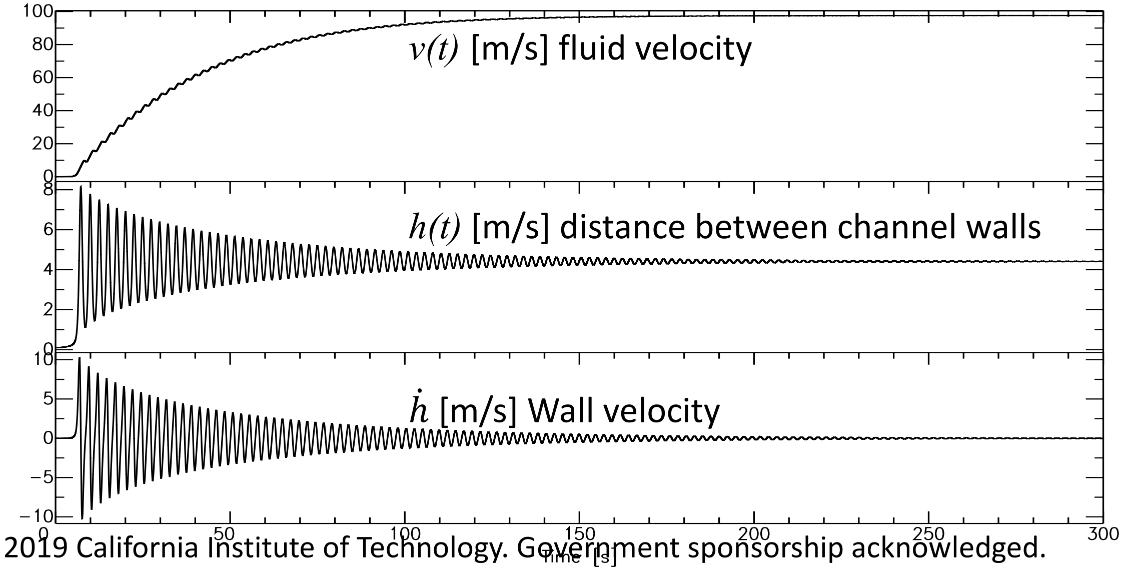
## Model inputs correspond to physical properties of Mars

- $g_M$ = 3.711 — Mars g, 3.711 [m/s$^2$]
- $D$ = 60000.0; — Crack Depth [m]
- $p_1\_p_2$ — Ratio p1/p2
- $p_2 = \rho \times g_M \times D$ — Pressure in exit reservoir [Pa] = lithostatic
  $p1 = p_2 \times p_1\_p_2$ — Pressure in feeding reservoir [Pa]
- $k$ — Wall elasticity [Pa] (Channel Aspect Ratio)
- $\rho$ = 2700.0 — Wall density [kg/m^3] =~ (magma density)
- $A$ = 1E7 — Elastic damping [kg s]
- $\eta$ — Fluid viscosity [Pa s]
- $L$ = 500.0; — Channel length [m]
- $h_0$ — Channel equilibrium thickness [m]
- $M$ =~ $\rho \times L \times L$ — Wall mass [kg/m] (2D)

## Model outputs

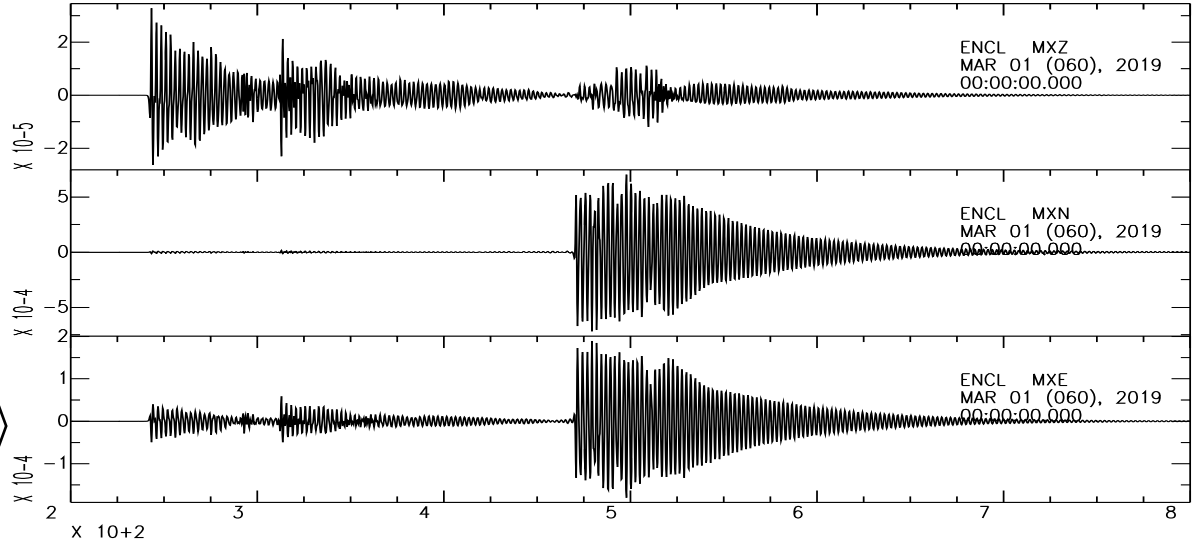



## Observational Constraints

- Observed waveforms
  - Amplitude
  - Duration
  - Frequency
- (Magma volume estimates)

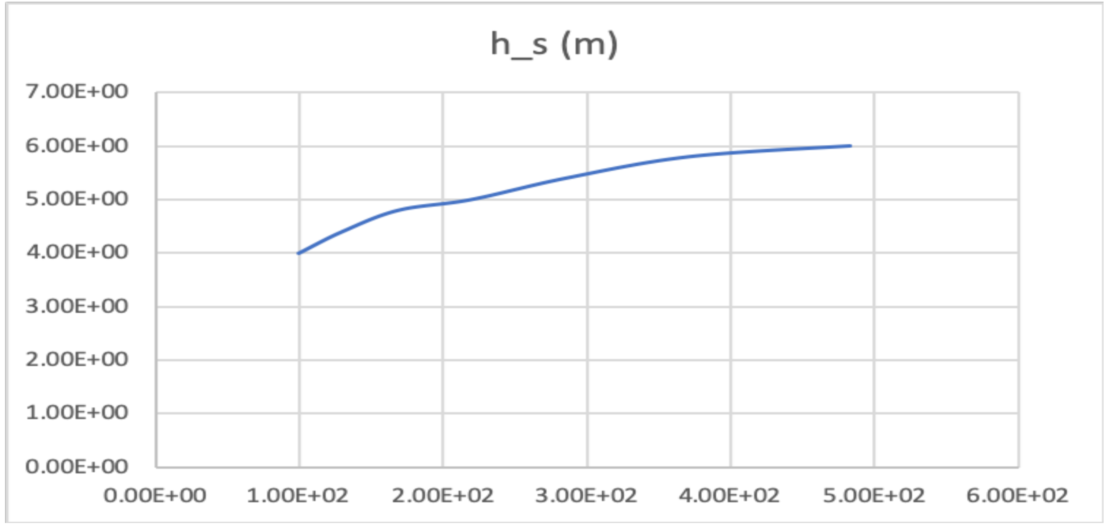
## Wave Propagation

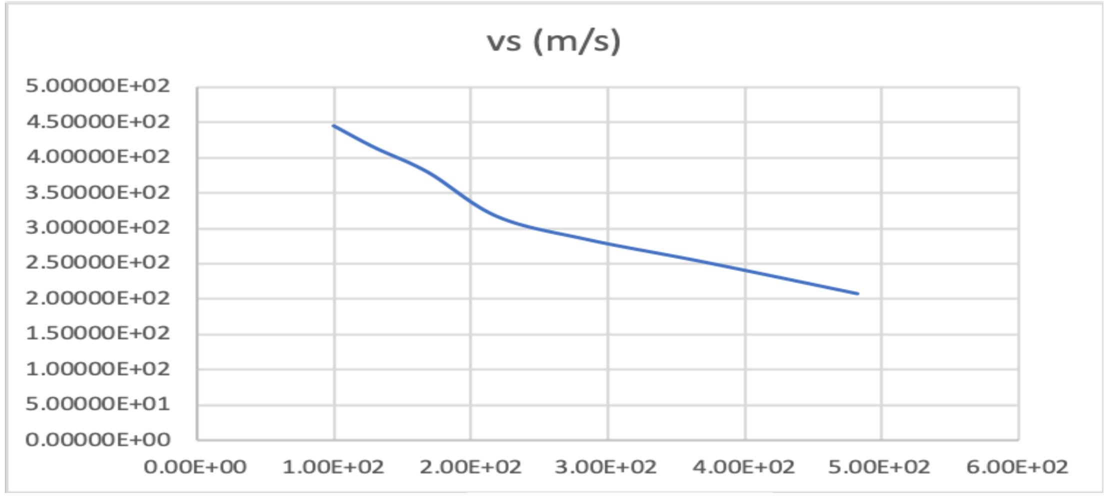
- Waveforms are synthesized using Instaseis databases created by Martin van Driel for the MQS blind test using the EH45Tcold model with two different crusts.
- Source is input with source time function defined by dh/dt from model runs, but normalized. Moment is defined with a “slip” value based on summed peak-to-peak variation of h. Fault area is defined with a 10 to 1 aspect ratio compared with L.



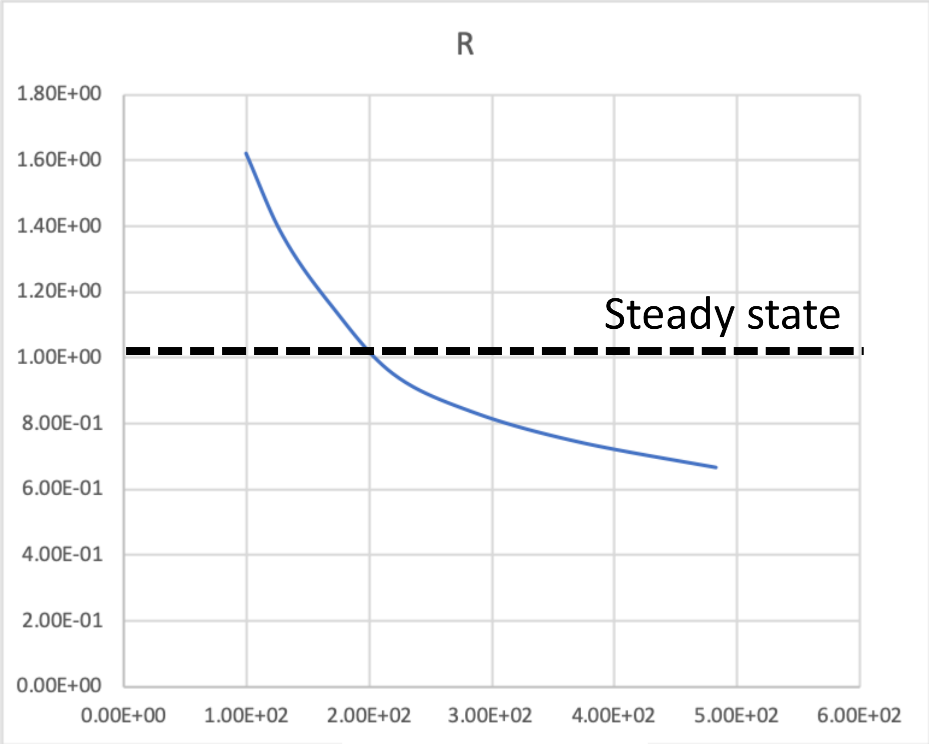
# Narrowing Down the Model Parameters Trade Space

(1) Since the observed events are intermittent and finite we limit the parameters trade space to a small perturbation about steady state conditions.



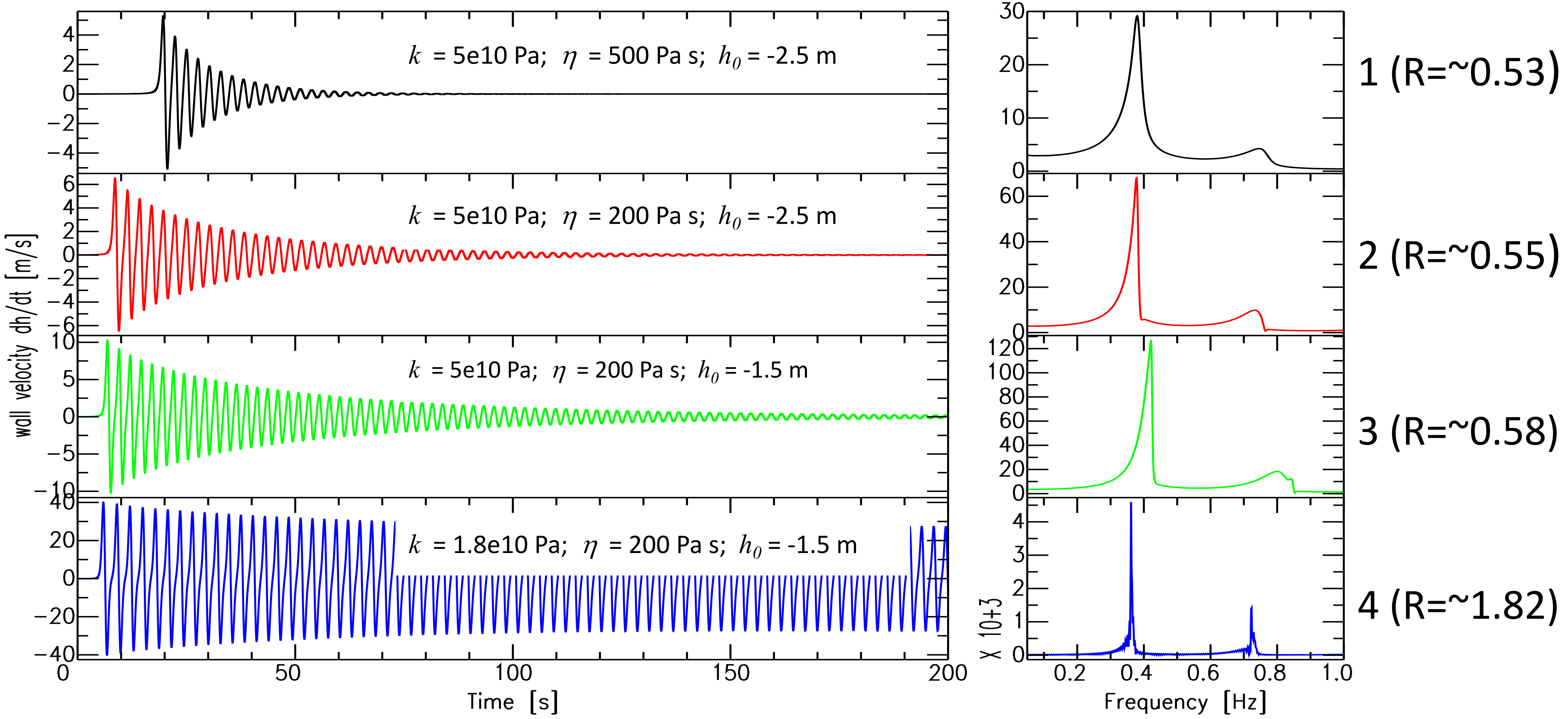

$\eta$ = 200 [Pa s]



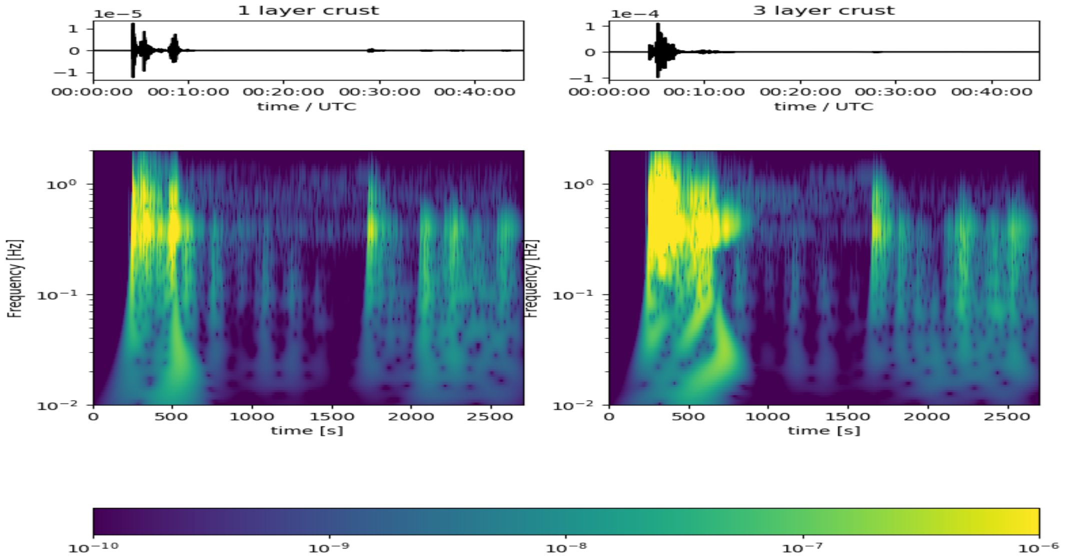

$\eta$ = 200 [Pa s]

(2) Once the parameters space is thus limited we will further narrow it down to the subset of models that are consistent with observations.

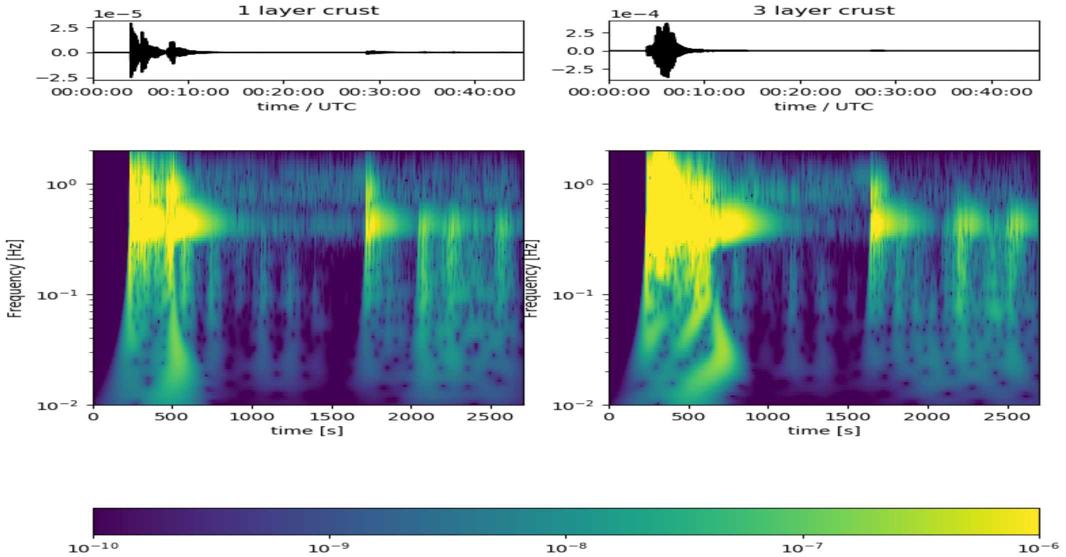
# Sample Model Runs



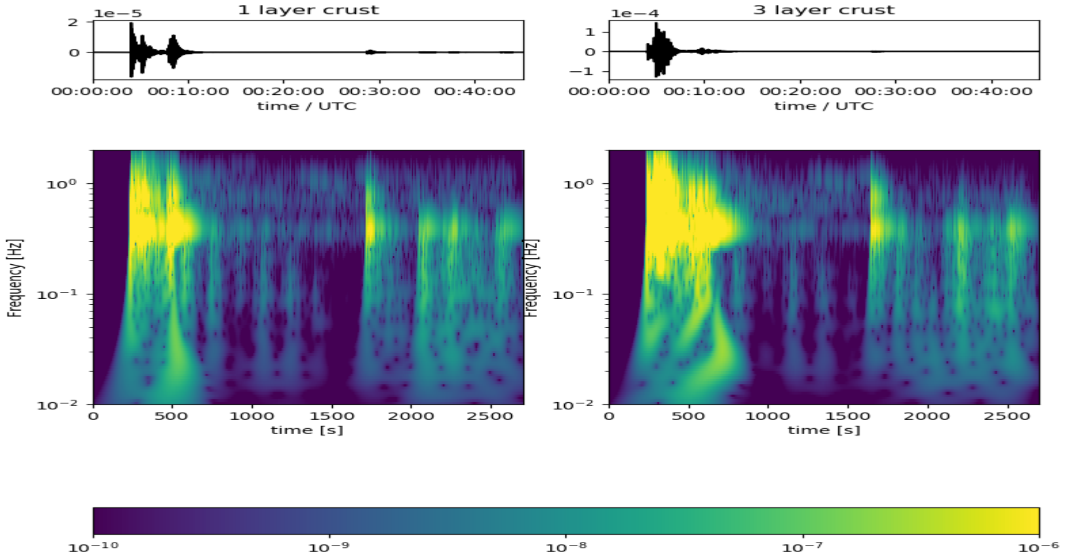
1


1e−5
1 layer crust
time / UTC
1e−4
3 layer crust
time / UTC
Frequency [Hz]
time [s]
Frequency [Hz]
time [s]

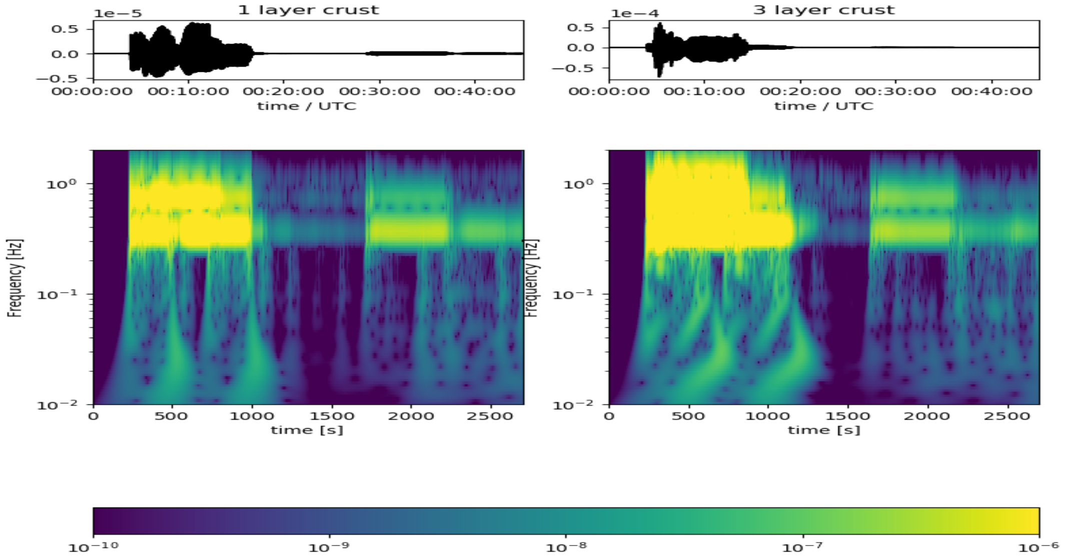
3


1e−5
1 layer crust
time / UTC
1e−4
3 layer crust
time / UTC
Frequency [Hz]
time [s]
Frequency [Hz]
time [s]

2


1e−5
1 layer crust
time / UTC
1e−4
3 layer crust
time / UTC
Frequency [Hz]
time [s]
Frequency [Hz]
time [s]

4


1e−5
1 layer crust
time / UTC
1e−4
3 layer crust
time / UTC
Frequency [Hz]
time [s]
Frequency [Hz]
time [s]

# Summary

- It is likely that most of the observed signal can be modeled by a volcanic tremor model with realistic physical parameters
- However, it is impossible to uniquely conclude that the observed events are induced by magma motion.
- Future work: Complete a comprehensive exploration of the parameter space and explore the range of geodynamic conditions that can support them.
- Combine with analysis of Cerberus (Jacob & Perin + Golombek)